

Fuel Cells for Distributed Power



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**Arctic Energy Technology Development
Laboratory**

**DOE Distributed Energy Road Show, Anchorage,
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Outline



- ⌘ Arctic Energy Technology Development Laboratory at UAF
- ⌘ R&D and Alternative Technologies
- ⌘ Fuel cells
- ⌘ Wind
- ⌘ Solar in Alaska
- ⌘ Geothermal
- ⌘ Conclusions

Arctic Energy Technology Development Laboratory



- ⌘ Created by a Congressional Earmark
- ⌘ Funded through DOE, NETL in Fossil Energy
 - ☐ Allow research in both traditional Fossil Energy areas as well as remote electrical systems
- ⌘ Money flows to UAF, but industry participation is encouraged

Request for Proposals



⌘ Proposals in Two Areas, Fossil and Remote Energy

⌘ Attracted a total of 150+ pre-proposals in 3 proposal calls

☒ Oil, gas and coal

☒ EOR, CO2 Sequestration, Hydrates, Gas pipeline, coal bed methane, coal combustion, environmental issues

☒ Remote Electrical

☒ Wind, Fuel Cells, Small Hydro, Thermoelectric, Hybrid systems

AETDL Structure



⌘ Independent structure to allow funding of projects in any area of the University

☑ INE, SME, GI, AG, UAA

⌘ Office Staffed by:

☑ DOE--Brent Sheets

☑ UAF--Dennis Witmer

☑ SAIC--Charles Thomas

Alaskan Electrical Energy Conference



⌘ First held in Fairbanks, September 2002

☒ 300 attendees, 100+ papers

☒ Attended by

☒ Alaskan Utilities

☒ University and NL researchers

☒ State and Federal policy makers

☒ Equipment suppliers

☒ Village Residents

⌘ Second conference to be held in Talkeetna, April 27-29, 2004



The R&D Process



⌘ A new idea

☑ Is this good science?

⌘ Laboratory Bench top

☑ Does the physics work?

⌘ Laboratory breadboard

☑ Systems evaluation

☑ Thermodynamic efficiency

The R&D process



⌘ Prototype

- ☒ System packaging (alpha unit)

⌘ Initial Field testing

- ☒ Cost

⌘ Pre-commercial units

- ☒ Reliability

⌘ Commercial units in niche markets

- ☒ Cost reduction

⌘ Mass production

- ☒ Incremental improvement

The NASA R&D Process



⌘ NASA Technology Readiness Level

- ☒ 1) Basic Principles observed and reported
- ☒ 2) Technology concept formulated
- ☒ 3) Analytical and experimental proof of concept
- ☒ 4) Component and/or breadboard verification in laboratory environment
- ☒ 5) Component and/or breadboard verification in a relevant environment
- ☒ 6) System model or prototype demonstration in a relevant environment
- ☒ 7) System prototype demonstrated in a flight environment
- ☒ 8) Actual system completed and “flight qualified” through test and demonstration
- ☒ 9) Actual system “flight proven” on operation flight

What is an alternative technology?



⌘ Conventional technologies are the ones we use every day

- ⌘ Internal combustion engines

- ⌘ Grid generated electricity

 - ⌘ Large scale hydro

 - ⌘ Natural gas turbines

 - ⌘ Coal fired boilers

 - ⌘ Nuclear power plants

- ⌘ Batteries

- ⌘ Boilers

⌘ Alternative technology is anything else

Why are alternatives not the conventional technology?



☒ Cost

- ☒ Most efficient technology is not necessarily the most cost effective technology

☒ Reliability

- ☒ Longevity
- ☒ Reparability
- ☒ Training of service personnel

☒ State of Development

- ☒ New technologies could be developed to become conventional technology

What are drivers to new technology?



⌘ Environmental Issues

- ☑ Global Warming

- ☑ Pollution

⌘ Potential rising cost of fossil energy

⌘ Cost reduction

Efficiency

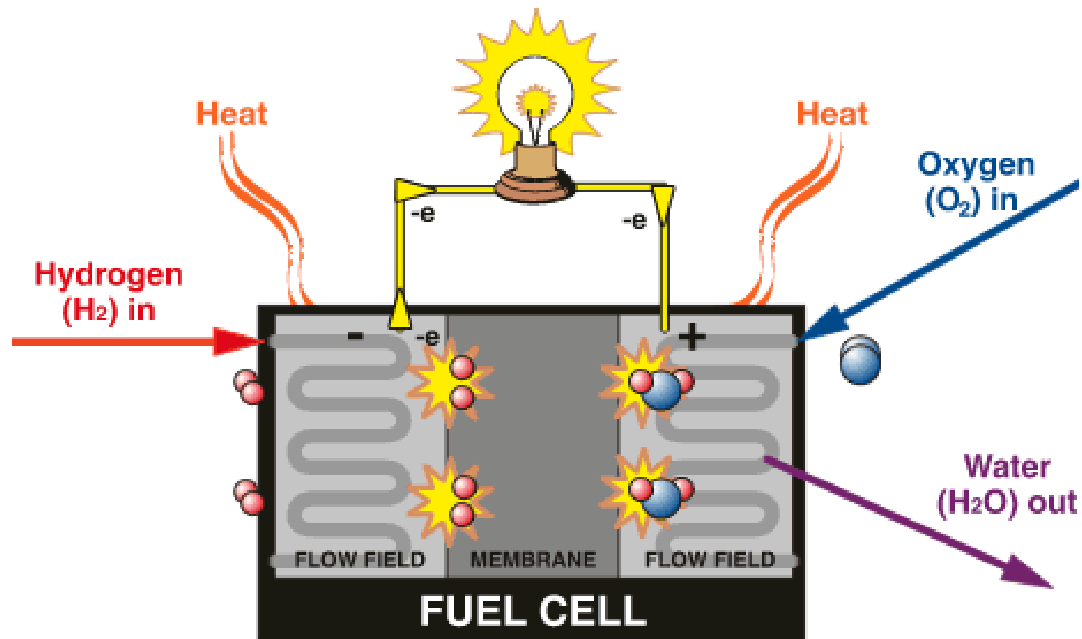


- ⌘ A measurement of how well a device converts the energy of a fuel into useful work.
- ⌘ Higher efficiency means lower fuel costs
- ⌘ Higher efficiency often comes at higher capital cost
- ⌘ The highest efficiency device may often not be the most commonly available technology

What is a fuel cell?

- ⌘ A device that converts the chemical energy in a fuel directly to electrical energy.
- ⌘ Requires fuel flow and oxygen flow, electrodes, and an electrolyte
- ⌘ Half cell reactions
 - ⊠ $\text{H}_2 \rightarrow 2\text{H}^+ + 2\text{e}^-$
 - ⊠ $\text{O}_2 + 4\text{e}^- \rightarrow 2\text{O}^{+2}$

Fuel cell basics



Parts of a fuel cell stack



⌘ Electrodes

- ☑ site of electrochemical reaction

⌘ Electrolyte

- ☑ Allows transfer of ions between anode and cathode

⌘ Electrical Conductors

- ☑ Allows transfer of electrons to external circuit

Advertised Advantages



- ⌘ Few moving parts (in the stack)
- ⌘ Clean (when operating on hydrogen)
- ⌘ Efficient (at low power)
- ⌘ Cost effective (in mass production)
- ⌘ Reliable (projected)

Possible disadvantages



- ⌘ Susceptible to impurity contamination
 - ☑ Electrode poisoning
 - ☑ Conductor corrosion
- ⌘ Air flow requires blower or compressor
 - ☑ There are moving parts to move air
- ⌘ Hydrogen management
- ⌘ Cost

Parts of a fuel cell system



- ⌘ Fuel cell stack
- ⌘ Air handling device
- ⌘ Fuel handling device
- ⌘ Fuel conversion device
- ⌘ Heat management system
- ⌘ DC to AC converter (inverter)
- ⌘ Control system

Electrical issues



- ⌘ Electricity needs to be generated and consumed simultaneously
- ⌘ Electrical loads vary with time
- ⌘ Electrical systems must load follow
- ⌘ Fuel cells operating on hydrocarbon fuels must use batteries or be grid connected for maximum efficiency

Fuel conversion



- ⌘ Fuel cells use hydrogen as fuel
- ⌘ Pure hydrogen is not found in abundance in nature
 - ☐ Energy storage vs. fuel
 - ☐ Most hydrogen produced in US is from Natural Gas
- ⌘ Total system efficiency must count conversion of water or hydrocarbon to hydrogen
- ⌘ A hydrogen infrastructure does exist, but hydrogen is still significantly more expensive than other hydrocarbon fuels.

Reformers



- ⌘ A device to convert a hydrocarbon fuel to a hydrogen rich gas stream
- ⌘ Uses part of the energy of the fuel for the conversion process
- ⌘ Operate at high temperature (800C)
- ⌘ Produce CO₂ as byproduct
- ⌘ Efficiency of 35 to 80%
- ⌘ Do not load follow well

Fuel Cells



⌘ Five types

- ☑ Alkaline

- ☑ Phosphoric Acid

- ☑ Molten Carbonate

- ☑ Solid Oxide

- ☑ Polymer Exchange Membrane

Phosphoric Acid



- ⌘ Largest installation in world at Anchorage Post Office
- ⌘ Stack degradation within a few years
- ⌘ Capital cost of \$3000/kw, life of 5 years gives capital cost of 7.8 cents / kW-hr
- ⌘ Net efficiency of about 35%
- ⌘ Status: Commercial (maybe), in niche markets
 - ☐ Issue: Long term stack reliability, cost

Solid Oxide Fuel Cells



- ⌘ Westinghouse Successfully demonstrated 200 kW units for 16,000 hours on Natural Gas
- ⌘ Building factory, will deliver 200 kW units @\$4500 per kW, starting in 2006 (???)
- ⌘ Working on 5kW system with FCT
- ⌘ Efficiency of 50% net electrical on NG
- ⌘ Status: Pre commercial
 - ☒ Issue: Cost of manufacturing



Results to date with 5 kW FCT SOFC



- ⌘ Unit delivered 10 months late
- ⌘ Started on August 1, 2003
- ⌘ Producing 4.2 kW DC power, >50%
- ⌘ Operating continuously since startup, except for one scheduled outage
- ⌘ Best performance from small scale fuel cell in our program

Issues with FCT SOFC



- ⌘ Needs N₂-H₂ mixed gas for startup
- ⌘ Needs electrical power for start up
- ⌘ Operates on Natural Gas
- ⌘ Unit is physically large and heavy
- ⌘ Still very expensive
- ⌘ Units are still not commercially available

Molten Carbonate



- ⌘ Technology in initial field demonstration phase (early 1990's)
- ⌘ Projected to be more cost effective than other FC
 - ☐ Low Cost materials
- ⌘ Still a few years away from commercialization
- ⌘ Status: Pre commercial
 - ☐ Issue: Stack lifetime

State of the PEM



⌘ Technology for transportation

- ☒ Only fuel cell technology with high energy density
- ☒ Very good load following on hydrogen


⌘ Field demonstrations not succeeding

- ☒ Membrane lifetime issues
- ☒ Efficiency issues
- ☒ Fuel reformer issues
- ☒ Cost!!!

⌘ Status: Prototype

- ☒ Issues: Reliability, efficiency, cost

Fuel Cell System Efficiency (at UAF)



- ⌘ Stack Efficiency
- ⌘ Balance of Plant
- ⌘ Reformer
- ⌘ Inverter
- ⌘ Batteries

PEM Efficiency



- ⌘ Stack Efficiency 60%
 - ⌘ BOP Efficiency 85%
 - ⌘ Reformer Efficiency 35-65%
 - ⌘ Inverter Efficiency 90%
 - ⌘ Batteries 90%
 - ⌘ Overall efficiency <25%
-
- ⌘ Conclusion: PEM fuel cells in distributed configuration is less efficient than grid!

Fuel Cell summary



⌘ Fuel cells are real

☑ Physics and chemistry are based on real science

⌘ Despite decades of R&D, fuel cells are not yet ready for prime time

⌘ Niche markets for fuel cells will likely develop before mass markets